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Art. XV.—*On the Dacite-Granodiorite Contact Relations in the Warburton Area.*

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(With Plates XVIII. and XIX.)

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(Note.—Numbers in brackets, thus—No. (1,515)—refer to sections in the University Collection.)

Introduction.

The contact relations of dacite and granodiorite constitute an important feature of the geology of the Warburton area.(2) and have been found worthy of a detailed study. Two localities exist where these relations can be observed:—(1) in and immediately south of Warburton township, and (2) in the Nyora estate, on the ridge and western slopes of Mt. Toole-be-wong.

The only previous work done on these metamorphic aureoles is by Professor Skeats, who visited both localities in 1909.(7) He recognised the general similarity between the gneissic contact aureole at Warburton, and that at Selby,(6) as well as the intrusive relation of granodiorite to dacite at Nyora, despite the absence there of gneissic rocks, in which respect this latter contact zone is similar to dacite-granodiorite contacts in the Macedon district.(8)

The Nyora Contact Metamorphic Zone.

The Nyora contact zone of itself would scarcely furnish sufficient evidence to establish the intrusive relation of the granodiorite to the dacites. Gneissic developments are quite absent except for rare xenoliths of dacite found in the granodiorite. The dacite shows alteration only for a foot or two from the granitic margin, and such alteration is merely an incomplete changing of the hypersthene to biotite, with a slight development of schistosity.

The contact is found here at 2,400 feet elevation, the dacite forming a thin shell over the granodiorite. It is evident that the granodiorite has been only recently exposed, and the weak contact effect lies in the fact that it marks the most upward progress, and hence the most feeble activity of the granodiorite.

The Silurian sediments are found metamorphosed to hornfels and to a very pure quartzite, No. (1,515), along the western margin of the granodiorite.

The Warburton Contact Metamorphic Zone.

The township of Warburton is built upon a narrow tongue of dacite which crosses the Yarra at this point, and comes into contact with a large granodiorite massif about a quarter of a mile south of the River Yarra.

The part of the contact aureole which is described has an east-west trend, and is about 1½ miles in length. It has an apparent width at its western end of over three-quarters of a mile, but is generally less than a quarter of a mile wide. Its true width is from 100 to 200 yards. The apparent width is due to the Yarra having cut a deep gorge parallel to the contact, and at the western end of the contact the hidden granodiorite surface shelves down relatively gently, and at a slight angle to the actual surface, so that only a thin shell of metamorphosed dacite remains, forming the outcrop. This enables careful study of the progressive metamorphism to be made. The geological features and the approximate zoning of the aureole are illustrated in the accompanying maps (Pl. XIX., Fig. 1).

At Selby only the hypersthene-dacite enters the granodiorite aureole, but at Warburton several rock types do so. In addition there is a wide sedimentary contact zone.

The irregular patches of coarsely gneissic dacite at Selby are absent. The Warburton "gneiss" is a fine-grained porphyroblastic rock, and occurs as a regular inner zone of the aureole. The occurrence of a patch of anthophyllite-garnet-rock in the latter area is also a new feature.

The aplitic and pegmatitic dykes of the Selby contact are repeated, but the post-granodiorite hornblende-porphyrite dyke facies is absent, unless the pre-granodiorite felspar-hornblende-porphyrite-dykes of Warburton are to be regarded as its equivalent.

A. The Igneous Rocks and their Alterations.

The rock types metamorphosed by the granodiorite are (1) the hypersthene-dacite; (2) the felspar-hornblende-porphyrite; (3) the α-quartz-biotite-dacite. The soda-rhyolite is within the outer limit of the contact aureole, but shows no sign of metamorphism.

The Hypersthene Dacite.

This exhibits progressive metamorphic alterations as the granodiorite is approached. The more distinct " stages " are described below.

1. *The Initial Stage.*—In the normal dacite the hypersthene phenocrysts are very generally bordered by a narrow granulitic rim of green, chloritic biotite. In this initial stage of metamorphism, Section No. (2,438) (Pl. XVIII., Fig. 1) a new granular phase of brown biotite and quartz (?) has formed between the old, outer, green rim and a remnant of the nucleus of the fresh hypersthene which still remains. In places the granules of the brownish biotite phase have aggregated to form flakes of biotite, all within the green rim. The formation of such flakes is heralded by the appearance of brown spots. In some crystals the brownish zone has widened to such an extent that the hypersthene nucleus has disappeared entirely. The green outer rim, while remaining distinct, also alters to a brown colour. The groundmass remains perfectly glassy or cryptocrystalline, showing flow structure, and the plagioclase phenocrysts are fresh and clear. Some pyrrhotite and a trace of chalcopyrite are introduced.

2. *" Spotty "-Schist Stage.*—In this stage the glassiness of the groundmass has given place to a patchy " spottiness " and a development of free quartz. The spottiness is reflected in the hand specimen. Individual plagioclases are sometimes clotted together in aggregates with these newly developed quartz grains, and with biotite flakes, forming mosaics.

The original hypersthene crystals are represented by aggregates of straw yellow to brown biotite flakes, which are generally minute in size, and are often associated with clots of structureless biotite. The ilmenites, so characterically included in the fresh hypersthene, are now surrounded with secondary biotite, and in many cases have themselves reacted to form biotite (2,441).

A very small quantity of green hornblende is present as small flakes or granules in the groundmass, and, rarely, small garnets are seen associated with the biotite.

3. *Schistose Stage.*—In the central part of the contact zone the groundmass loses its "spotty" appearance, owing to a more general growth in grain size.

The individual flakes in the biotite clots have grown in size (Pl. XVIII., Fig. 2), but decreased in number, the clots remaining about the same size, and showing an increased parallelism. Ilmenite is quite absent, and there is no further development of garnet. The plagioclase phenocrysts vary from the perfectly unaltered to the highly sericitised. They often contain numerous inclusions of biotite, suggesting recrystallisation.

Quite large irregularly shaped porphyroblasts of quartz are developed, sometimes as mosaics. A little green hornblende, as flakes of minute size and larger crystals, is again present.

4. *Coarsely Schistose Stage.*—Still nearer the granodiorite the groundmass becomes more coarsely microcrystalline, and a schistose texture is developed by the parallel arrangement of strings of biotite flakes.

Porphyroblasts of quartz are prominently developed. These crystals show evidence of incipient granulation, in that they sometimes form coarse mosaic clots. Green hornblende is far more prevalent, particularly in medium-grained, sometimes idiomorphic porphyroblasts. It develops at the expense of the biotite, with which it is generally associated. The individual flakes of biotite are still coarser than in the preceding stage, and the clots are elongated lenticles. The felspars are still fresh, but appear to be crowded together owing to the growth size of the groundmass. They are commonly injected by granular quartz, and show evidence of marginal solution and compression.

5. *Gneissic Stage.*—This stage is found in a fairly narrow zone in immediate contact with the granodiorite. It is a fine-grained orthogneiss ("gneiss" in that it is completely recrystallised). The groundmass is finely granular and very even grained. The coarse patches and inequalities of the groundmass of the previous stage are completely absent. Parallel orientation of the numerous minute biotite flakes is strongly pronounced. The parallel or "banded" structure curves about the "phenocryst" remnants and porphyroblasts, as in augen structures.

Biotite is still a prominent constituent, both in the groundmass and as lenticular aggregates, drawn out parallel to the foliation. The individual flakes are now moderate sized crystals. The hornblende has become equal or superior in quantity to the biotite, and is frequently idiomorphic (Pl. XVIII., Fig. 3). It is commonly associated with the biotite lenticles. Some of the biotite associated with the hornblende appears to be of a different character to the "clotted" biotite, and from its fringing position to have formed from the hornblende, depositing the excess silica as quartz. Circular clots of granular hornblende apparently formed by the aggregation of hornblende granules produced by the reaction of biotite granules with the groundmass, are also a feature. These are often stained a red-brown by reaction to form secondary biotite or from iron staining.

The plagioclases are generally recrystallised, and have grown by molecular absorption of neighbouring phenocrysts, so that they are much fewer in number, but larger in size (up to 5 mm. diameter). Many of them have an idiomorphic contour, and have a core of decomposed felspar, often rich in inclusions of biotite and hornblende, with an outer rim of fresh, clear felspar, of more sodic character.

The quartz porphyroblasts have been granulated down into the groundmass. Layers of granular quartz are found sheltering against the rim of plagioclase crystals, and "stringers" of granular quartz are seen, oriented parallel to the foliation. Ilmenite is absent.

Anthophyllite-Garnet-Rock.

This rock has been found only in one small patch, about 1 chain square, of the contact zone, and has formed from the hypersthene-dacite, under special conditions. The meagre evidence available points to its being the product of a "double metamorphism" firstly by the felspar-hornblende-porphyrite, and secondly by the granodiorite.

1. *Initial Stage.*—What apparently represents the initial stage of this alteration is recorded in Section Nos. (2,400–2,402) (Pl. XVIII., Fig. 4) cut from the contact of the felspar-hornblende-porphyrite with the hypersthene dacite on the southern slopes of Ben Cairn.[2] In these sections the hypersthene crystals retain their original biotitic rim—here a brown one (cf. p. 184). The hypersthene of the interior of the crystals is entirely replaced, in some cases by granular biotite, but equally commonly by sheaves of a pleochroic, colourless to plum-brown mineral, which has a high double refraction, and appears to be anthophyllite; i.e., the metamorphic action of the porphyrite has been to induce a paramorphic change in the ferromagnesians.

These sections have not been matched in the Warburton locality, perhaps owing to insufficient exposure, or possibly because similar specimens are absent. At this locality the contact zone appears narrower than usual, probably owing to an increase in the angle between the slopes of the surface and the granodiorite surface.

2. *Incipient Anthophyllite-Rock.*—This rock, Section No. (2,425), is from the margin of the outcrop which is farthest from the granodiorite. It has been strongly recrystallised, and to some extent foliated. The groundmass is quite irregular, varying from a crypto- to a coarsely micro-crystalline texture, and consisting of quartz, felspar, biotite, ilmenite, and anthophyllite. Mosaic patches and "stringers" of clear, inclusion-free quartz are prevalent. A characteristic feature is the presence of patches of quartz, full of minute inclusions of biotite, ilmenite, and anthophyllite needles. It seems probable that the clear quartz is of an earlier generation.

Anthophyllite occurs in small plates and sheaves of needles, but it is far more generally scattered throughout the groundmass as small needles or bundles of them. It is commonly associated with biotite. Ilmenite occurs in quite fresh grains and crystals, and is rarely associated with secondary biotite. It is equally common in the groundmass or as inclusions in patches of fibrous or granular anthophyllite, or clots of biotite after hypersthene. The original biotite tends to become structureless. The plagioclase phenocrysts remain fresh, but are corroded, and are often crowded together by the recrystallisation. Some have grown a border of fresh felspar.

3. *Anthophyllite-Rock.*—In this specimen, Section No. (2,426), taken from the centre of the outcrop, anthophyllite is the dominant ferromagnesian, occurring as plates, sheaves, and granular aggregates, and commonly associated with biotite. Anthophyllite needles commonly fringe the patches of inclusion-rich. "biaxial" quartz. The more granular crystals have not the rich plum colour of the large flakes and crystals.

The plagioclases occur as crystals, and as coarsely granulated mosaics, associated with clear, interlocking quartz grains. They show flexing and shearing, and parallel orientation by pressure (?) has often brought them into contact. Fresh ilmenite is frequently found included in the anthophyllite, or in the groundmass, and structureless, partially altered biotites occur. In phases the rock is locally holoblastic in texture.

4. *Anthophyllite-Garnet-Rock.*—The greater part of this small outcrop contains garnet, in varying quantities. In one specimen, No. (2,427) (Pl. XVIII., Fig. 5), anthophyllite and to a lesser extent garnet dominate, almost to the exclusion of biotite. The garnet is a pink type, forming sub-lenticular porphyroblasts often with clear rims around a granular or fractured core. It commonly contains inclusions of quartz, anthophyllite needles, large ilmenite grains, and zircons. It has the appearance of having formed from some reaction which set free quartz, since granular quartz is commonly associated with it, either as inclusions or as a border to the garnet. The plagioclases are less numerous than in the

anthophyllite rock, and are generally more altered and intruded by the groundmass, which is of a variable texture, and consists of quartz, anthophyllite, biotite, and felspar. Fresh ilmenites (or iron ore) are prevalent.

In another example, No. (2,428), there is an increase in the proportions of anthophyllite and garnet, while the plagioclase crystals are practically absent. Foliation is well marked.

The origin of the iron ore is well illustrated in specimen No. (2,429) (Pl. XVIII., Fig. 6). Large crystals of primary biotite are seen, which are much corroded, and have discharged iron ore and quartz granules in considerable quantities. The same specimen illustrates the rapid variation of the relative quantities of the constituents, and in two sections 4 inches apart, Rosiwal volumetric analyses are as follows:—

	I.	II.
Anthophyllite	27%	20%
Garnet	17%	8%
Bytownite ($Ab_{70}An_{30}$)	9%	13%

There is also a noticeable unmeasured increase in the proportion of biotite in II. This variation may be due to irregularity of reaction, but seems more probably due to local migration of constituents.

The garnet is often found wedged between anthophyllite and plagioclase, and its development seems to be at the expense of those two minerals.

There is a general similarity between these metamorphic changes and those recently described by Sugi,[9] in which anthophyllite-garnet-rock is apparently developed from a hypersthene-bearing amphibolite. The anthophyllite-rock is of unusual occurrence, the common alteration of the hypersthene being to a green hornblende. Sugi considers that the anthophyllite develops from the hypersthene under special conditions of metamorphism which are produced by "local increase of vapour pressure, and the presence of volatile matter."

The Felspar-Hornblende-Porphyrite.

This rock enters the contact area in two places:—(i) a dyke running diagonally south-west, from just east of the Warburton Railway Station, and (ii) a dyke running slightly east of south, just west of Scotchman's Creek. Although distinctive in its normal condition, it is difficult to distinguish between the gneissic facies of the porphyrite and the gneissic facies of the hypersthene dacite.

The normal rock is porphyritic, containing large phenocrysts of labradorite and andesine set in a groundmass of glass, quartz, and granules of biotite. Ferromagnesian phenocrysts are subordinate to the felspar. They consist of yellow biotite, and a green to blue-green (soda ?) hornblende, and the latter is generally replaced by aggregated flakes of biotite (cf.[2]). Ilmenite grains with biotitic rims are prevalent, and granular quartz, as stringers or aggregates, is present frequently.

1. *Initial Stage.*—As the outer limit of the contact aureole is left behind the groundmass becomes cryptocrystalline and sometimes "patchy." Lenticles of granulated quartz mosaics occur more frequently, and the biotite granules of the groundmass tend to aggregate. The plagioclase phenocrysts show a considerable degree of alteration and clouding, and some show partial granulation. The hornblende is much less in quantity than the biotite. Occasional fractured phenocrysts of quartz occur.

2. *Schist Stage.*—Section No. (2,457) cut from the central part of the aureole shows a development of parallel orientation of both groundmass and phenocrysts. The former is glassy to cryptocrystalline in texture. Hornblende dominates over biotite, replacing the clots and crystals of the latter with more or less idiomorphic porphyroblasts of green hornblende. Ilmenite grains are bordered by leucoxene. The larger plagioclase phenocrysts are coarsely granulated, and are intermingled, in clots, with the newly developed hornblende. The felspars are usually reduced in size, and have a distinctive dark rim. Granular quartz is occasionally associated with the felspars.

3. *Gneiss Stage.*—Section No. (2,458) is an example from the inner contact zone close to the granodiorite, and to the anthophyllite-garnet-rock. It consists of elongated lenticles of biotite flakes and hornblende crystals, and remnants of plagioclase phenocrysts, set in a coarse micro-crystalline groundmass of quartz, felspar, and biotite. This groundmass is very granular in appearance, and tends to form fine-grained mosaics of quartz. Remnants of coarse mosaics, fading into finer mosaics may represent original quartz porphyroblasts. The general parallelism of the groundmass is broken by the porphyroblasts and phenocrysts. There is an obvious tendency for "augen structure" to form in such cases. Hornblende dominates over a reddish-brown biotite. The plagioclases sometimes show clear zones of secondary rim growth, with partially decomposed cores, and equally commonly they have dark rims. Fresh crystals of felspar show shearing, fracture, solution and granulation marks.

The α-Quartz-Biotite-Dacite.

The α-quartz-biotite-dacite forms the most westerly outcrop of the igneous lavas which enter the contact zone. Section No. (2,454), from the hill behind the Warburton Chalet, illustrates the more altered phase of this rock. The characteristic alteration is the copious development of green hornblende. This is found as granules, small idiomorphic crystals and large clots. It is commonly associated with yellow biotite, which it replaces. The original primary biotite crystals are commonly frayed at the edges, and partially absorbed. The clotted aggregates of biotite flakes (probably after enstatite) in the original rock are the first to form hornblende. Some of the felspar phenocrysts appear to have been recrystallised, and the quartz crystals show incipient granulation. There is a complete lack of schistose structure.

The α-quartz-biotite-dacite is also found near Pheasant Creek, at the eastern end of the contact zone. In this locality, Section No. (412), hornblende is absent. The rock has suffered considerable recrystallisation, so that the phenocrysts are ragged, and elongated parallel to the schistose foliation. The grain size is microcrystalline and coarser and muscovite is developed. This section, and also No. (431), from closer to the granodiorite, represent the gneissic zone of the aureole with regard to the α-quartz-biotite-dacite.

A section No. (410) of a xenolith in the granodiorite, presumably of this dacite originally, is a strongly foilated biotite-felspar gneiss, the constituents showing marked coarse banding. The felspar consists of perthite, anorthoclase (?) and oligoclase. Quartz is of rare occurrence, and the biotite is rich in zircons. A complete recrystallisation has occurred, giving rise to an intergrowth of biotite flakes of very variable size with the large interlocked sodic felspars, and to an almost complete exclusion of quartz and calcic constituents. As a xenolith, this specimen is unique among those collected.

B. The Sedimentary Rocks and their Alteration.

The types of Silurian sediments metamorphosed by the granodiorite are blue slates, mudstones, and sandstones. The products of the metamorphism are chiastolite slates, "spotted" hornfels and andalusite-hornfels, and quartz-muscovite hornfels, respectively. The outcrops are not such as to permit the progressive metamorphism of any one bed to be traced, but it is possible to correlate the changes for any one rock type.

The blue slates are transformed into chiastolite-slates, Section No. (475). The square chiastolite crystals often contain a nucleus of andalusite. Apart from these porphyroblasts of chiastolite, the rock is strongly spotted by the development of patches of andalusite (?) or quartz (?).

The mudstones show two alterations, according as they are quartzitic or argillaceous. The quartzitic mudstones are the dominant type, and are converted into "spotted" hornfels. This is a very fine-grained rock, with an occasional coarse patch of matrix. The rock is crowded with colourless lenticular "spots," which give a biaxial positive figure and appear to consist of granular quartz. These spots include granules of biotite and ilmenite, and are often fringed with tiny biotite flakes. They show a sub-parallel orientation of their long axes, and often "coalesce." Brown biotite flakes are concentrated between the spots. A little muscovite is present.

The argillaceous mudstones have been found represented by an andalusite-quartz-tourmaline-rock, Section No. (2,446), as their most intensely altered facies. This rock consists of quartz, andalusite, tourmaline, iron, muscovite in this order of abundance. The andalusite is a colourless variety, showing perfect cleavage. The smaller, irregular shaped crystals of it occur in patches, associated with granular quartz and ilmenite grains. Brown and blue tourmaline are common as crystals, or as "cement" between grains. Grains of iron ore are very numerous, though small, and muscovite in moderate sized flakes is prevalent.

The impure sandstones appear as quartz-muscovite-hornfels, Section No. (471), with the quartz grains commonly cemented by an iron oxide, and with the muscovite subordinate, but copiously developed.

Mineralogical Changes.

The mineral changes produced by the metamorphism of the dacites are summarised below:—

I. Hypersthene reacts with orthoclase to form biotite and quartz. This reaction has been explained previously.[1, 6]

II. Hypersthene under certain conditions undergoes a paramorphic change to produce anthophyllite. Pressure probably is an important factor in this alteration.

III. Anthophyllite reacts, probably with calcic plagioclase, to form a pink garnet (almandine-pyrope) and quartz.

IV. Ilmenite reacts to form biotite, as previously described.[1, 6]

V. Biotite reacts to form ilmenite (or magnetite) and quartz.

VI. With "intratelluric" cooling, in the felspar-hornblende-porphyrite dyke on Ben Cairn, hornblende is replaced by biotite. The biotite forms clots of small flakes where the reaction was partially inhibited by viscosity preventing local diffusion, and primary crystals where the cooling was slowest. In the contact zone hornblende on cooling appears to give rise to biotite and quartz.

VII. Biotite reacts, probably with quartz in the groundmass, to form common green hornblende, at a temperature below 750° C., if a sufficient pressure is attained.

Associated with these reactions is a growth, followed by later granulation, of quartz porphyroblasts, and a molecular migration and recrystallisation of plagioclase phenocrysts.

Mechanics of Intrusion.

It appears that the granodiorite entered into its present position in a quiet manner. The Silurian strata appear free from any dynamic disturbance by the rising magma. Three large quarries in the "spotted" hornfels, one south of Old Warburton, and the other two near the "debouchures" of Postman's Creek and Big Pat's Creek, permit observation of the undisturbed strata close to the contact. There is no sign of puckering or distortion. The general regularity of the igneous part of the contact aureole supports this view. The most satisfactory method of intrusion to fit the evidence would be by magmatic stoping (after Daly).

Marginal assimilation undoubtedly played a minor part. Near the head of Pheasant Creek the marginal hornfels is partially assimilated for about 5 feet from the granodiorite. The marginal granodiorite is full of rounded and partially assimilated xenoliths of dacite and of gneissic sediments.

The lack of porphyritic textures in the granodiorite suggests that it came into its final position in a probably viscous-fluid state, and crystallisation occurred generally in a more or less eutectic manner, the fine grain size resulting from the viscosity. The xenoliths appear to have fallen into the magma before crystallisation commenced, or viscosity arrested their sinking. The majority of these inclusions cannot have sunk more than 100 feet.

The Intensity of the Metamorphism at Warburton.

The controlling factors during the metamorphism appear to have been pressure and temperature. Temperature appears to have been the dominant factor, but neither can have developed great intensity.

The pressure was of a compressional nature, and was not of a sufficient strength to distort the sedimentary strata. Its more marked effect on the igneous rocks is not the result of any inferior strength in these, nor yet of greater local pressure. In the igneous types, instability developed in certain of the constituents as the result of an infusion of molecular energy by the rise in temperature and a molecular rearrangement towards stability under the new conditions, followed. It is to be expected then that any pressure acting during this rearrangement would impress itself on the rock in an increasing degree corresponding to an increasing degree of rearrangement. The sediments, however, in most cases, presented a stable complex at the temperature induced by the metamorphism, and were generally unaffected. Recrystallised xenoliths of the sediments, however, show a perfect gneissic foliation, for the same reason as the dacites do; and the "spotted" hornfels show a tendency towards a parallel orientation.

The temperature at which the metamorphism occurred cannot have been very high. The most altered, innermost rocks in the contact aureole may be regarded as having experienced the maximum induced temperature. The minerals developed in such rocks act as temperature indicators. In the Warburton igneous rocks common green hornblende is the typical development, and garnet and anthophyllite are found in one patch; in the sediments the only minerals developed from the original constituents are andalusite, chiastolite and muscovite. These all indicate low temperatures, but unfortunately no data as to the temperature of formation of andalusite or hornblende appear to be available. Kozu, Yoshiki, and Kani[5] state that, in an atmosphere of nitrogen, green hornblende alters to basaltic hornblende at 750° C. We may assume then that the hornblende was developed below this temperature. In zones of contact metamorphism where the temperatures were intense (1,200° C.), e.g., Christiania,[3] pyroxene, plagioclase, and cordierite are formed. The absence of these minerals may be regarded as evidence for low temperatures.

Mineralisation.

Locally considerable mineralisation has occurred. Pneumatolysis has played a major part in the introduction of material. Tourmaline, both blue and brown, is found in pegmatites and in the metamorphosed sediments. Pyrite, pyrrhotite, chalcopyrite, and rarely galena, are introduced into the joint planes of the granodiorite, and occasionally into the contact rocks. Some gold has accompanied them.

Gold and stibnite are found in quartz reefs along Hoddle's Creek, cassiterite is found along the Mississippi Creek, and also near Beenak, where it is associated with kaolinised granodiorite. Wolfram occurs with tourmaline in quartz veins and as stockwerks in the granodiorite at the head of Britannia Creek;[4] and a 12-inch vein of galena is recorded from McMahon's Creek. Gold colours are found throughout the granitic country. It seems probable that gold occurs in a very finely disseminated fashion throughout the granodiorite massif: but there seem to be very few localities in which any concentration of gold has taken place.

Between Backstairs Creek and the Scotchman's Creek the granodiorite is decomposed to a gravel of quartz and mica (bleached biotite) for a depth of over 100 feet. Whether this is due to removal of felspars by percolating surface waters, or to pneumatolytic agents is unknown. This area of decomposed rock has been very thoroughly combed for gold, but with very little reward.

Comparison with other Victorian Contact Zones.

In the Bulla contact-zone,[10] cordierite and plagioclase were developed in the sediments, so that the temperature must have been considerably higher than that experienced at Warburton. At Selby[6] no hornblende was developed, despite the presence there of hornblende in the granodiorite. This suggests that temperature alone is not a sufficient factor in the formation of hornblende. Differential pressure is considered as a probable agent in the development of gneissic patches at Selby, but the general compressional forces developed throughout the contact zone were much less intense than those set up at Warburton.

Previous workers have been at a loss to explain the variability of the dacite-granodiorite contacts, viz., that the Macedon and

Nyora contacts are weakly developed, while that at Selby is more strongly marked, and, as now seen, the Warburton aureole is still further developed. A clue to the explanation appears to lie in the degree of erosion or "roof removal" in each locality.

It seems safe to assume that the more abysally the metamorphism occurred, the higher the temperature and the pressure, and the greater the changes resulting, other factors being equal. Then, according to the degree of "de-roofing" or the depth of erosion in the contact zone, we should find a weakly or strongly developed metamorphism. At Nyora the granodiorite is only just de-roofed, so that the most feebly developed metamorphism is exposed. At Selby the de-roofing has gone further, and at Warburton the Yarra River has cut deeply into the contact zone.

Another factor determining the intensity of metamorphism will be the thickness of dacite penetrated by the intruding granodiorite magma.

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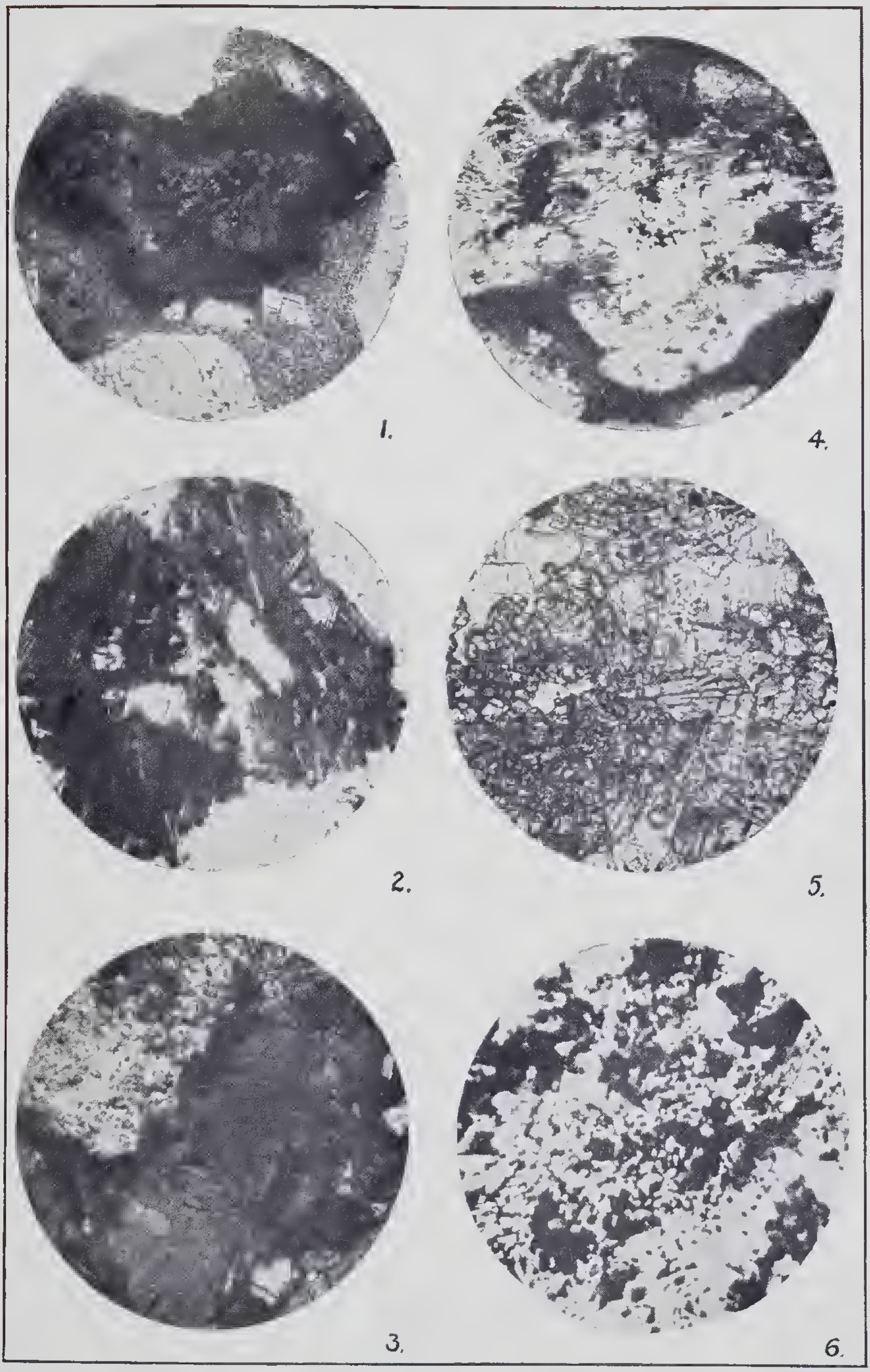
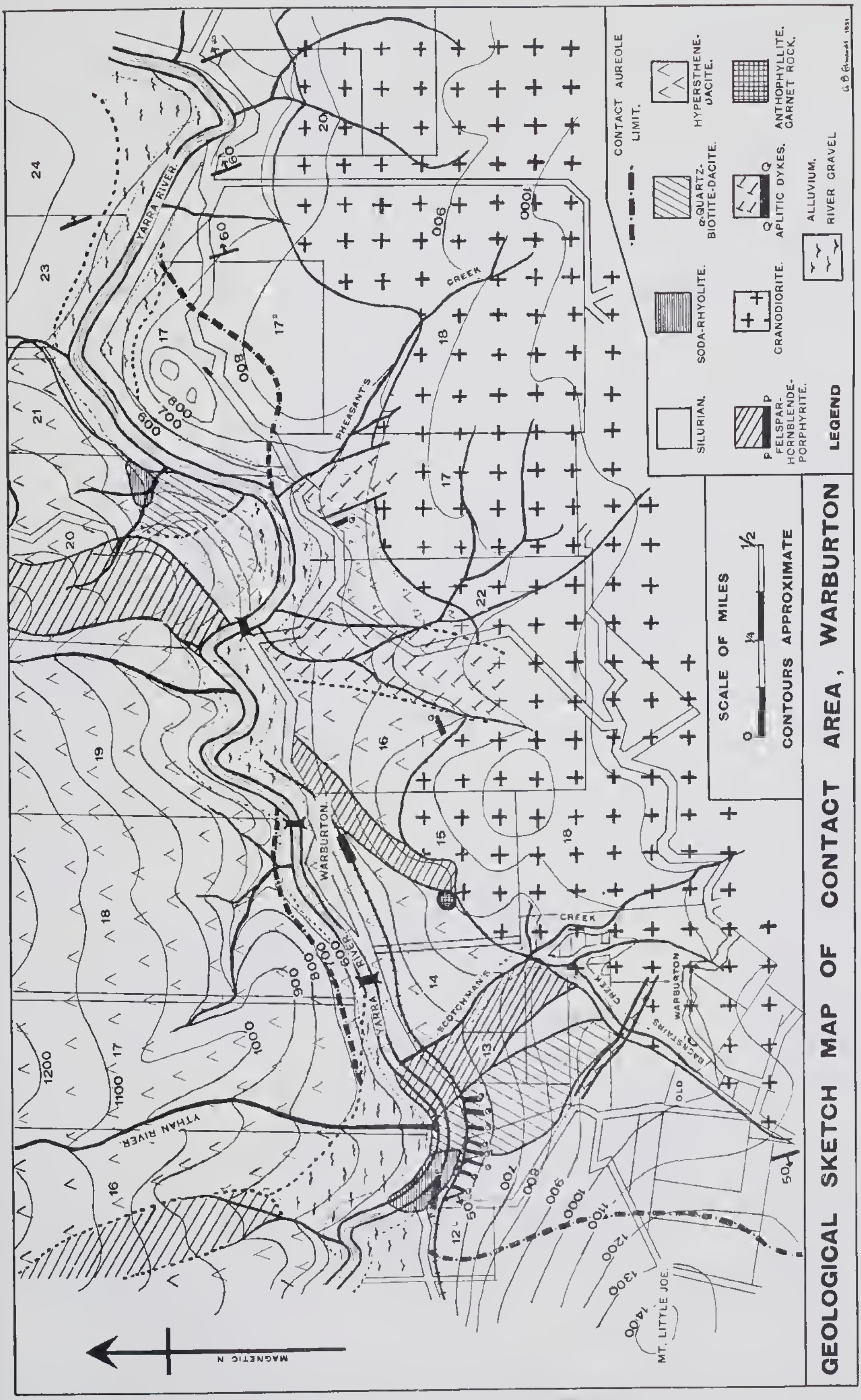
Explanation of Plate XVIII.

1. Hypersthene-dacite. Nucleus of fresh hypersthene, surrounded by granular and crystalline biotite to which it is altering. The dark rim is granular biotite which formed during consolidation of the rock and pre-dates the biotite formed within it by the metamorphism. (x. 65.)
2. A clot of biotite flakes which have replaced the hypersthene (from the hypersthene-dacite ortho-schist). (x. 65.)
3. Green hornblende replacing biotite in the ortho-gneiss stage of the hypersthene-dacite. (x. 65.)
4. Hypersthene forming fibrous anthophyllite. The black rim consists of granular biotite, and was formed during the consolidation of the rock. (cf. 1.) (x. 65.)
5. Anthophyllite-garnet-rock, formed from the hypersthene-dacite, showing the garnet porphyroblasts, and plates of anthophyllite. (x. 65.)
6. A mosaic intergrowth of quartz and iron ore deposited by the decomposition of biotite, in the anthophyllite-garnet rock. (x. 65.)



Miss J. Wilson-Smith, Photo.


GEOLOGICAL SKETCH MAP OF CONTACT AREA, WARBURTON
LEGEND
SILURIAN.
SODA-RHYOLITE.
α-QUARTZ-BIOTITE-DACITE.
CONTACT AUREOLE LIMIT.
FELSPAR-HORNBLENDE-PORPHYRITE.
GRANODIORITE.
APLITIC DYKES.
HYPERSTHENE-DACITE.
ANTHOPHYLLITE, GARNET ROCK.
ALLUVIUM, RIVER GRAVEL
SCALE OF MILES
0
1/4
1/2
CONTOURS APPROXIMATE
MAGNETIC N
YARRA RIVER.
YTHAN RIVER.
WARBURTON
PHEASANT'S
CREEK
SCOTCHMAN'S
BACKSTAIRS
OLD WARBURTON
MT. LITTLE JOE.

13801

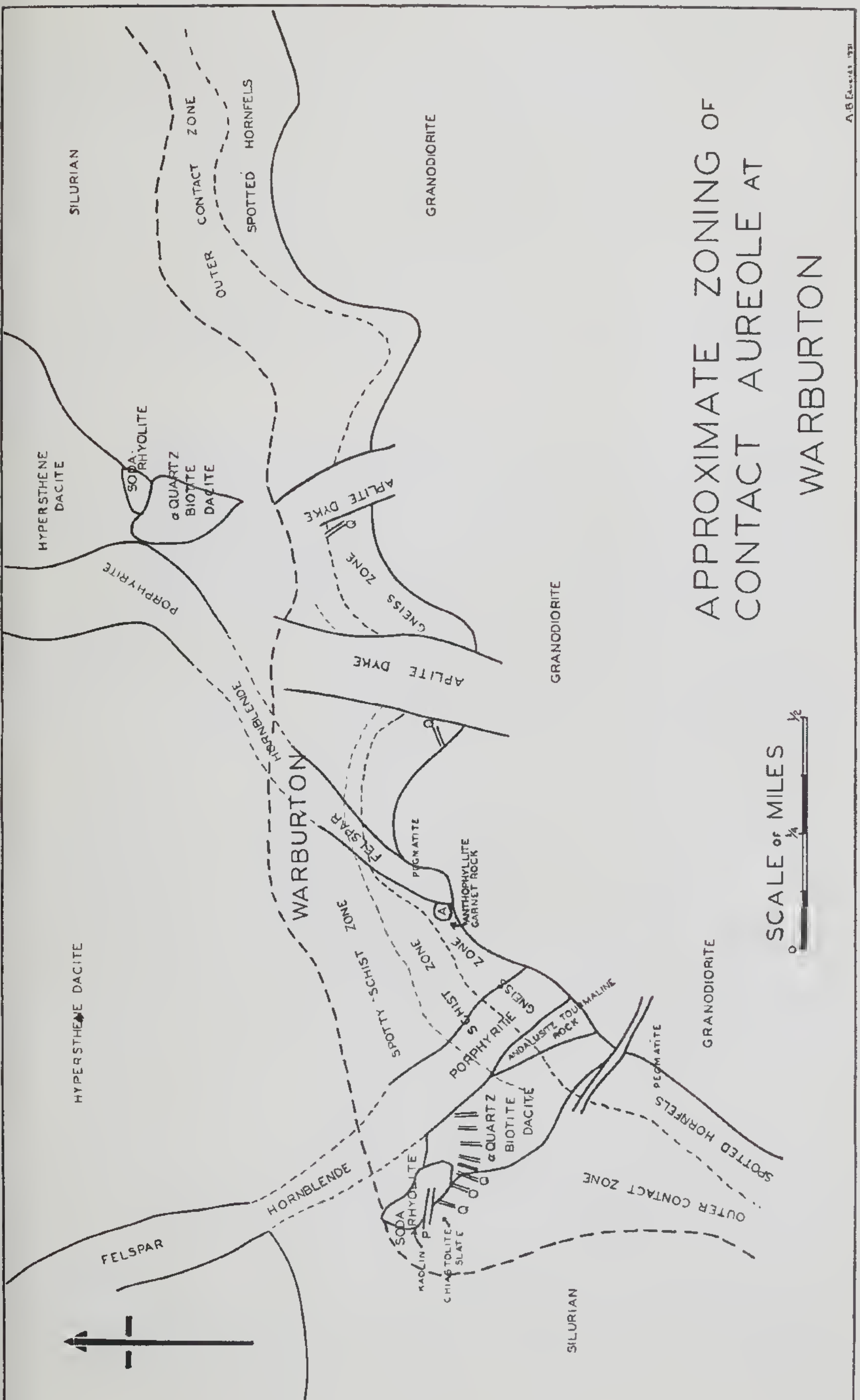

APPROXIMATE ZONING OF CONTACT AUREOLE AT WARBURTON
SCALE of MILES
0
¼
½
SILURIAN
GRANODIORITE
HYPERSTHENE DACITE
OUTER CONTACT ZONE
SPOTTED HORNFELS
SODA RHYOLITE
α QUARTZ BIOTITE DACITE
PORPHYRITE
APLITE DYKE
GNEISS ZONE
HORNBLENDE
WARBURTON
FELSPAR
PEGMATITE
ANTHOPHYLLITE GARNET ROCK
SPOTTY SCHIST ZONE
SCHIST ZONE
ANDALUSITE TOURMALINE ROCK
CHIASTOLITE SLATE
KAOLIN

Fig. 1.